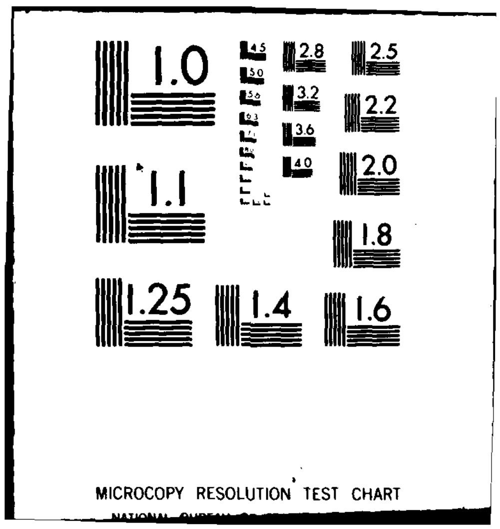
AD-A117 689 OBSERVATORIO DEL EBRO TORTOSA (SPAIN) IONOSPHERIC SECTION F/G 4/1
LUNAR VARIATION OF SEVERAL IONOSPHERIC PARAMETERS.(U)
SEP 81 L F ALBERCA, J O CARDUS, E GALDON AFOSR-79-0114
UNCLASSIFIED SCIENTIFIC-2 EOARD-TR-82-12 NL

END
DATE
FILMED
8-82
DTIC


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

AD A117689

SCIENTIFIC REPORT N° 2

# LUNAR VARIATION OF SEVERAL IONOSPHERIC PARAMETERS

L. F. Alberca S. I.
J. O. Cardús S.I.
E. Galdón S. I.

OBSERVATORIO DEL EBRO
Ionospheric Section
ROQUETES
(Tarragona)Spain

EOARD-TR-82-12

GRANT Nº AFOSR 79-0114 B 30 Sept. 1981

SCIENTIFIC REPORT Nº 2

# LUNAR VARIATION OF SEVERAL IONOSPHERIC PARAMETERS

L.F. Alberca, s.I.
J.O. Cardús, s.I.
E. Galdón, s.I.

OBSERVATORIO DEL EBRO
IONOSPHERIC SECTION
ROQUETES
(Tarragona) Spain

THE RESEARCH REPORTED IN THIS DOCUMENT HAS BEEN SPONSORED IN PART BY THE AIR FORCE GEOPHYSICAL LABORATORIES THROUGH THE EUROPEAN OFFICE OF AEROSPACE RESEARCH OAR UNITED STATES AIR FORCES.

## ABSTRACT

The first four harmonics of the diurnal lunar variation and the semimonthly lunar tide for two years TEC data at Ebro and Hamilton,and for some other ionospheric parameters at Ebro have been obtained. For the parameters with sufficient number of data, the lunar harmonics for the different seasons have also been obtained. The relation between the dirunal lunar variation of the height and the electron density of the maximum of the F2 layer seems to be solar dependent with a change of the phase at about 1000 SLT. The diurnal solar variation of the semimonthly lunar tide is also discussed.

CONTENTS

## INTRODUCTION.

In a previous report (Alberca et al. 1980) the total electron content (TEC) data of Hamilton (subion. 38.7º N, 70.7º W) corresponding to 1976 and the data of the Faraday rotation of 1978 of Ebro Observatory (subion. 37.1º N, 1.5º W), were analized by the Chapman-Miller method as described by Malin and Chapman (1970) in order to obtain the lunisolar tidal components in both stations. Also the semimonthly lunar tide and its solar diurnal variation at these two stations were obtained. The results show the need of extending the analysis to a larger ammount of data to reduce the calculated errors.

In the present report we shall apply the Chapman-Miller method to the data of two years of the same stations:1975-76 of Hamilton (Kindly supplied by Dr. Klobuchar) and 1978-1979 of Ebro. We shall analyse also, by the same method, the 1979 data of the critical frequency of the F2 layer (foF2), the "parabolic height" of the F2 layer (hpF2), the electron density of the maximum of the F2 layer (Nm=1.24*F2**2) and the slab-thickness ( $\tau$ = TEC/Nm), and we shall compare the results obtained for these four parameters with those of the TEC for the same year.

## RESULTS AND DISCUSSION

### SEMIDIURNAL LUNAR VARIATION.

#### Total Electron Content.

The amplitudes and phases of the solar and lunar components of the TEC daily variation for two years at Hamilton and Ebro are given in tables I and II. The data of Hamilton correspond to the 1965-1976 periode and the data of Ebro to 1978-1979. The probable error and percentages of the amplitudes with respect to the mean value of the data considered in each analysis are also given. The analysis has been done for all data taken together and for the data distributed in three seasons: Winter,

ALL DATA
=========
530 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 64.3 | 558.7 | 4.6 | 243.6 | 1.1 | 9.4 | 5.0 | 15.1 |
| 2 | 13.5 | 117.3 | 3.0 | 83.7 | 1.7 | 14.8 | 3.2 | 126.8 |
| 3 | 5.2 | 44.9 | 1.4 | 27.9 | 0.8 | 7.2 | 1.5 | 293.3 |
| 4 | 2.1 | 17.9 | 1.1 | 296.9 | 0.1 | 0.8 | 1.2 | 102.1 |

WINTER
======
192 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 81.6 | 637.9 | 8.5 | 251.5 | 1.3 | 9.9 | 9.3 | 347.9 |
| 2 | 25.1 | 196.2 | 4.1 | 82.4 | 2.5 | 19.2 | 4.3 | 131.8 |
| 3 | 7.0 | 54.5 | 3.3 | 15.4 | 1.1 | 8.7 | 3.4 | 298.1 |
| 4 | 6.2 | 48.3 | 2.2 | 253.5 | 0.2 | 1.9 | 2.3 | 170.6 |

EQUINOXES
==========
148 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 68.7 | 737.0 | 7.3 | 241.4 | 1.5 | 15.8 | 8.0 | 7.9 |
| 2 | 12.6 | 134.9 | 4.9 | 75.4 | 1.4 | 14.6 | 5.2 | 118.7 |
| 3 | 7.2 | 77.8 | 3.6 | 33.6 | 0.4 | 4.6 | 3.7 | 186.9 |
| 4 | 2.3 | 24.4 | 2.5 | 286.0 | 0.1 | 1.0 | 2.6 | 292.0 |

SUMMER
======
190 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 44.3 | 352.9 | 7.0 | 232.6 | 1.4 | 11.3 | 7.6 | 75.7 |
| 2 | 4.0 | 31.6 | 2.4 | 121.5 | 1.0 | 8.2 | 2.5 | 150.4 |
| 3 | 1.6 | 12.7 | 1.6 | 55.4 | 1.4 | 10.9 | 1.7 | 305.3 |
| 4 | 4.7 | 37.4 | 2.1 | 33.4 | 0.7 | 5.3 | 2.1 | 59.3 |

**Table I. -Solar and lunar components at Observatorio del Ebro for TEC data of two years (1978-1979).**

ALL DATA
========
718 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | SOLAR AMPLITUDE VAL. | SOLAR AMPLITUDE P.ERR | SOLAR PHASE DEG | LUNAR TERMS AMPLITUDE % | LUNAR AMPLITUDE VAL. | LUNAR AMPLITUDE P.ERR | LUNAR PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 71.7 | 46.1 | 0.24 | 242.5 | 1.1 | 0.7 | 0.26 | 19.6 |
| 2 | 6.4 | 4.1 | 0.29 | 75.7 | 2.4 | 1.6 | 0.30 | 165.8 |
| 3 | 6.3 | 4.0 | 0.11 | 21.1 | 0.2 | 0.1 | 0.12 | 316.5 |
| 4 | 1.4 | 0.9 | 0.06 | 11.7 | 0.4 | 0.2 | 0.06 | 293.7 |

WINTER
======
233 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | SOLAR AMPLITUDE VAL. | SOLAR AMPLITUDE P.ERR | SOLAR PHASE DEG | LUNAR TERMS AMPLITUDE % | LUNAR AMPLITUDE VAL. | LUNAR AMPLITUDE P.ERR | LUNAR PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 82.7 | 48.8 | 0.53 | 251.9 | 1.7 | 1.0 | 0.58 | 48.4 |
| 2 | 28.7 | 16.9 | 0.44 | 58.5 | 1.4 | 0.8 | 0.46 | 196.2 |
| 3 | 3.3 | 2.0 | 0.19 | 344.1 | 0.5 | 0.3 | 0.20 | 47.7 |
| 4 | 5.1 | 3.0 | 0.14 | 216.7 | 0.2 | 0.1 | 0.14 | 340.9 |

EQUINOXES
==========
241 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | SOLAR AMPLITUDE VAL. | SOLAR AMPLITUDE P.ERR | SOLAR PHASE DEG | LUNAR TERMS AMPLITUDE % | LUNAR AMPLITUDE VAL. | LUNAR AMPLITUDE P.ERR | LUNAR PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 75.5 | 48.9 | 0.50 | 243.4 | 1.1 | 0.7 | 0.55 | 39.3 |
| 2 | 7.9 | 5.1 | 0.37 | 72.7 | 4.4 | 2.8 | 0.39 | 169.3 |
| 3 | 8.1 | 5.2 | 0.21 | 27.5 | 1.0 | 0.7 | 0.22 | 294.1 |
| 4 | 2.2 | 1.4 | 0.10 | 7.3 | 0.5 | 0.3 | 0.11 | 335.1 |

SUMMER
======
244 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | SOLAR AMPLITUDE VAL. | SOLAR AMPLITUDE P.ERR | SOLAR PHASE DEG | LUNAR TERMS AMPLITUDE % | LUNAR AMPLITUDE VAL. | LUNAR AMPLITUDE P.ERR | LUNAR PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 61.3 | 42.1 | 0.33 | 231.2 | 1.1 | 0.7 | 0.35 | 336.2 |
| 2 | 14.3 | 9.8 | 0.34 | 225.0 | 2.0 | 1.4 | 0.36 | 151.1 |
| 3 | 7.7 | 5.3 | 0.17 | 27.2 | 0.4 | 0.3 | 0.18 | 130.7 |
| 4 | 6.1 | 4.2 | 0.13 | 30.1 | 0.7 | 0.5 | 0.13 | 267.6 |

**Table II. -Solar and lunar components at Hamilton for TEC data of two years (1975-1976).**

equinoxes and summer. No previous filtering of data has been performed and the only data rejected are those belonging to days in which at least one hourly value is missing. The number of days included in each analysis is also given in the tables. The amplitudes and phases of the lunar components of the tables are those of the equation

$$L=\sum_{1}^{4} l_n \sin((n-2)t+2\tau+\lambda_n)$$

where "t" and "τ" designate respectively solar and lunar time.

As compared with the results of the previous report, the present results show a diminution of the probable error (as expected) in practically all harmonics, indicating a better accuracy. Only in two cases the errors have increased a little, and both cases correspond to winter: the 2nd harmonic of Hamilton and the 4th harmonic of Ebro. In these two cases also the solar errors increased. We can say that, as a whole, the lunisolar results of Ebro show an improvement, particularly in equinoxes where the second harmonic is now significant. The results of Hamilton on the contrary, are less satisfactory, because not only the error but also the amplitudes of the different harmonics have diminished, causing some of them to become not significant, as, for instance, in winter when no harmonic remains significant. An ulterior study of the data (particularly those of 1975 that probably have some discrepancies with the original ones) is needed to determine the cause of these results. Nevertheless, the results are consistent with the ones found for a year in the sense that most of the harmonics found with data of a year remain within the probable error circles of the corresponding harmonics found with data of two years.

The results found in the previous report, indicated that the lunisolar harmonics of Ebro in equinoxes were not significant and we suggested that the cause of it could be the change of possition of the focus of the dymamo ionospheric currents. Since the present results show that the second harmonic of Ebro at equinoxes is significant, this conclusion has to be revised.

In fig. 1 the harmonic dials of the lunisolar components

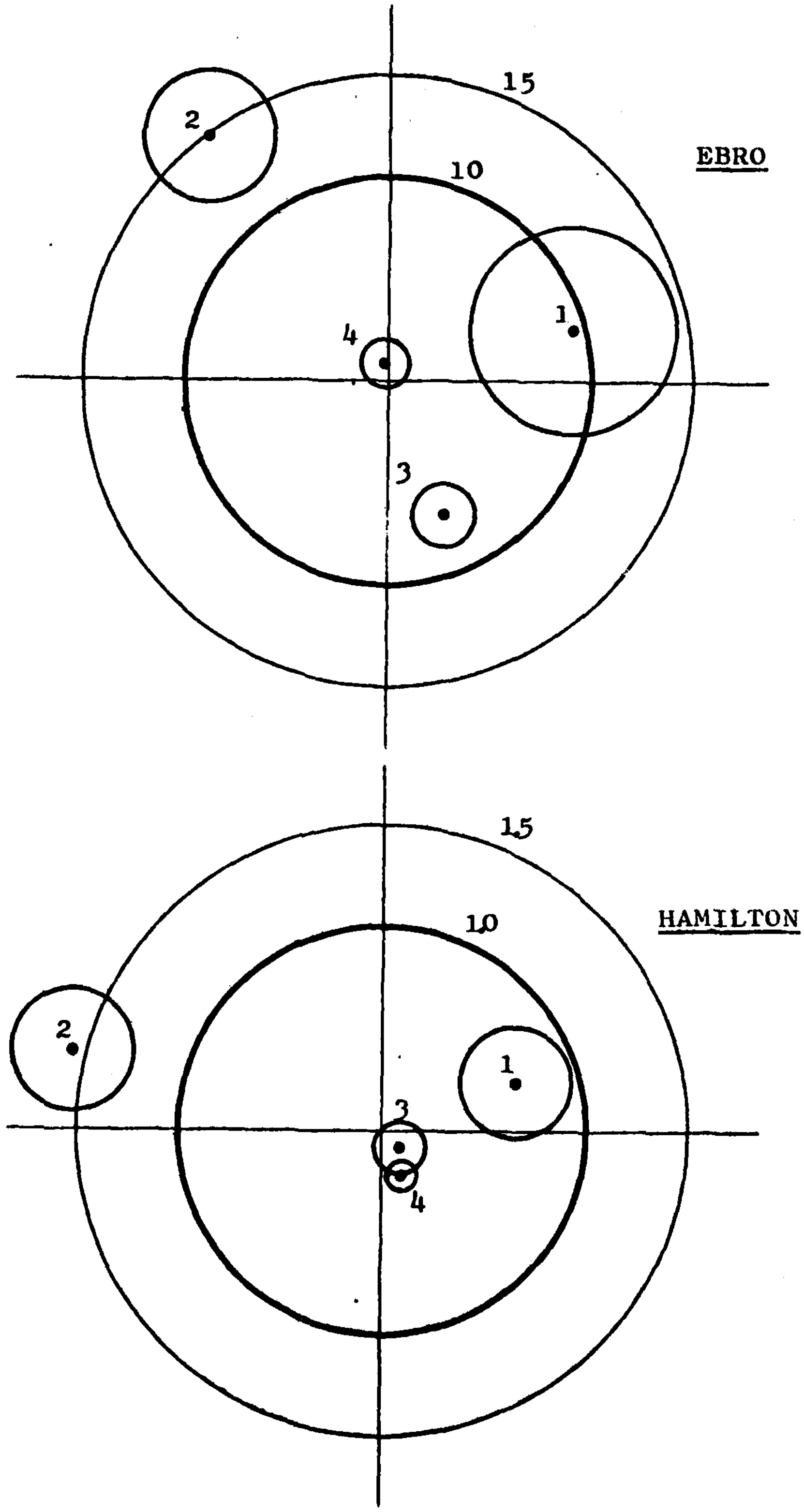



Fig. 1. - Lunar harmonics for TEC data of two years.

of Ebro and Hamilton are shown for comparison. As can be seen the second harmonic of Ebro is rotated clockwise a little more than 30º (that corresponds to 1hr) with respect to the second harmonic of Hamilton. With the data of only a year (cf. Alberca et al. 1981) the rotation was a little less than 30º. The other significant component of Ebro is the third one. It is also rotated clockwise with respect to the one of Hamilton, although the rotation is less than 30º and the difference of amplitudes are much bigger than in the case of the second harmonic. The other two harmonics are significant in Hamilton but not in Ebro. The first ones are very near from each other but the fourth ones are almost in opposite phase.

Taken the phase as the time at which the maximum variation occurs, as many authors do, the phase of the second harmonic at Ebro oscilates between 10hrs in summer and 11hrs in equinoxes, while at Hamilton it changes from 8.5hrs in winter to 10hrs in summer. These results are in agreement with the values found by other authors for the lunisolar variation of foF2 and NmF2.(Cfr. Matsushita,1967, Handa,1978,etc.).

Comparing the amplitudes of the second harmonic for the different seasons, we find that,at Ebro, the amplitude is larger in winter than in summer, (in agreement with Shatten and Mendillo(1980)) reaching an intermediate value in equinoxes. In Hamilton the maximum value is found in equinoxes and the minimum one in winter. Matsushita(1967) reports results of some midlatitudes stations where the amplitude of the second harmonic of foF2 is greater in summer than in winter, in agreement with the result of TEC in Hamilton.
The differences of the amplitude of the second lunar harmonic between winter and summer, confirm the results obtained with the data of one year.

## Comparison with other ionospheric parameters.

The results for the year 1979 in Ebro of the Faraday angle (proportional to TEC), the critical frequency of the F2 layer (foF2), the electron density of the maximum of the layer (Nm), The "parabolic heigth" (hpF2) and the slab-thickness ($\tau$) are sl ir ables III-VI. The results of the analysis of hpF2

ALL DATA

285 DAYS

| | Solar terms | | | | Lunar terms | | | |
|---|---|---|---|---|---|---|---|---|
| HARM | AMPLITUDE | | | PHASE | AMPLITUDE | | | PHASE |
| | % | VAL. | P.ERR | DEG | % | VAL. | P.ERR | DEG |
| 1 | 67.2 | 681.4 | 6.5 | 243.9 | 0.5 | 4.8 | 7.1 | 49.5 |
| 2 | 15.7 | 158.9 | 3.8 | 84.7 | 1.6 | 15.8 | 4.0 | 122.5 |
| 3 | 5.4 | 54.3 | 1.9 | 23.3 | 1.0 | 10.5 | 2.0 | 294.1 |
| 4 | 2.4 | 23.9 | 1.6 | 286.2 | 0.2 | 2.0 | 1.6 | 129.1 |

WINTER

115 DAYS

| | Solar terms | | | | Lunar terms | | | |
|---|---|---|---|---|---|---|---|---|
| HARM | AMPLITUDE | | | PHASE | AMPLITUDE | | | PHASE |
| | % | VAL. | P.ERR | DEG | % | VAL. | P.ERR | DEG |
| 1 | 81.1 | 804.8 | 10.5 | 249.8 | 0.6 | 5.7 | 11.4 | 244.5 |
| 2 | 24.5 | 242.8 | 4.6 | 83.1 | 2.0 | 19.9 | 4.9 | 125.7 |
| 3 | 7.5 | 74.4 | 3.8 | 13.0 | 1.1 | 10.7 | 3.9 | 301.5 |
| 4 | 6.0 | 59.6 | 3.2 | 250.2 | 0.2 | 1.7 | 3.3 | 198.1 |

EQUINOXES

70 DAYS

| | Solar terms | | | | Lunar terms | | | |
|---|---|---|---|---|---|---|---|---|
| HARM | AMPLITUDE | | | PHASE | AMPLITUDE | | | PHASE |
| | % | VAL. | P.ERR | DEG | % | VAL. | P.ERR | DEG |
| 1 | 67.3 | 901.9 | 15.6 | 240.7 | 4.6 | 61.6 | 17.0 | 354.6 |
| 2 | 13.6 | 181.6 | 9.2 | 82.8 | 2.8 | 37.2 | 9.6 | 142.4 |
| 3 | 6.7 | 90.3 | 5.3 | 27.8 | 0.6 | 8.2 | 5.5 | 207.3 |
| 4 | 2.8 | 37.4 | 4.6 | 288.4 | 0.6 | 7.7 | 4.8 | 11.3 |

SUMMER

100 DAYS

| | Solar terms | | | | Lunar terms | | | |
|---|---|---|---|---|---|---|---|---|
| HARM | AMPLITUDE | | | PHASE | AMPLITUDE | | | PHASE |
| | % | VAL. | P.ERR | DEG | % | VAL. | P.ERR | DEG |
| 1 | 48.8 | 395.5 | 10.5 | 235.4 | 2.1 | 17.2 | 11.5 | 113.8 |
| 2 | 5.9 | 48.2 | 4.8 | 99.3 | 0.1 | 0.7 | 5.0 | 15.6 |
| 3 | 1.6 | 13.0 | 3.1 | 77.2 | 1.5 | 12.3 | 3.2 | 312.7 |
| 4 | 5.1 | 41.6 | 3.3 | 35.2 | 0.7 | 5.4 | 3.4 | 107.7 |

**Table III. -Solar and lunar components at Observatorio del Ebro for TEC data of 1979.**

ALL DATA
========
232 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 35.3 | 31.9 | 0.4 | 246.0 | 0.5 | 0.5 | 0.5 | 248.2 |
| 2 | 7.4 | 6.7 | 0.2 | 103.2 | 0.7 | 0.6 | 0.2 | 152.7 |
| 3 | 7.0 | 6.4 | 0.1 | 32.8 | 0.4 | 0.3 | 0.1 | 327.9 |
| 4 | 2.1 | 1.9 | 0.2 | 296.0 | 0.1 | 0.1 | 0.2 | 107.3 |

WINTER
======
93 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 50.1 | 43.3 | 0.5 | 254.4 | 0.6 | 0.6 | 0.5 | 221.3 |
| 2 | 13.5 | 11.6 | 0.3 | 101.5 | 1.1 | 1.0 | 0.3 | 157.9 |
| 3 | 10.5 | 9.1 | 0.2 | 29.2 | 0.0 | 0.0 | 0.3 | 296.0 |
| 4 | 5.4 | 4.6 | 0.2 | 263.8 | 0.3 | 0.3 | 0.2 | 353.7 |

EQUINOXES
==========
92 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 32.0 | 30.4 | 0.8 | 239.5 | 1.7 | 1.6 | 0.8 | 346.4 |
| 2 | 4.8 | 4.6 | 0.3 | 106.9 | 0.8 | 0.7 | 0.3 | 155.8 |
| 3 | 6.5 | 6.2 | 0.3 | 34.5 | 0.2 | 0.2 | 0.3 | 349.5 |
| 4 | 1.6 | 1.6 | 0.3 | 344.8 | 0.2 | 0.2 | 0.3 | 77.7 |

SUMMER
======
47 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 16.6 | 14.7 | 0.7 | 222.8 | 1.2 | 1.1 | 0.6 | 124.8 |
| 2 | 1.2 | 1.1 | 0.5 | 109.2 | 0.7 | 0.6 | 0.5 | 243.0 |
| 3 | 1.8 | 1.6 | 0.3 | 62.0 | 0.8 | 0.7 | 0.3 | 312.6 |
| 4 | 3.0 | 2.6 | 0.3 | 36.6 | 0.3 | 0.2 | 0.3 | 140.3 |

Table IV. -Solar and lunar components at Observatorio del Ebro for foF2 data of 1979.

ALL DATA
========
232 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 65.9 | 735.9 | 11.01 | 248.9 | 1.4 | 15.4 | 11.99 | 255.7 |
| 2 | 15.2 | 169.4 | 5.13 | 94.0 | 1.4 | 15.1 | 5.39 | 139.8 |
| 3 | 11.3 | 125.9 | 3.55 | 27.1 | 1.0 | 11.1 | 3.69 | 321.0 |
| 4 | 3.1 | 35.0 | 3.84 | 265.3 | 0.3 | 3.7 | 3.96 | 147.9 |

WINTER
======
93 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 89.9 | 972.6 | 12.26 | 257.6 | 1.7 | 18.1 | 13.39 | 231.1 |
| 2 | 27.5 | 298.0 | 6.44 | 96.4 | 1.6 | 17.6 | 6.77 | 140.3 |
| 3 | 15.6 | 168.9 | 6.09 | 21.7 | 0.5 | 5.4 | 6.30 | 300.8 |
| 4 | 9.9 | 106.6 | 5.56 | 245.4 | 0.1 | 0.6 | 5.73 | 326.2 |

EQUINOXES
=========
92 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 61.0 | 739.5 | 21.36 | 242.6 | 3.3 | 40.5 | 23.26 | 338.3 |
| 2 | 9.6 | 116.7 | 8.11 | 90.6 | 1.9 | 23.0 | 8.55 | 150.5 |
| 3 | 11.2 | 135.8 | 7.06 | 30.6 | 0.6 | 7.1 | 7.33 | 329.6 |
| 4 | 1.5 | 17.6 | 7.66 | 328.1 | 0.3 | 3.4 | 7.89 | 77.0 |

SUMMER
======
47 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 32.1 | 321.1 | 14.29 | 224.3 | 2.9 | 28.6 | 15.63 | 107.8 |
| 2 | 2.2 | 21.8 | 10.25 | 64.1 | 1.6 | 15.8 | 14.73 | 238.2 |
| 3 | 2.8 | 27.5 | 5.84 | 60.2 | 1.6 | 15.6 | 6.07 | 318.5 |
| 4 | 5.9 | 58.5 | 6.70 | 40.5 | 0.8 | 7.6 | 6.90 | 134.1 |

Table V. -Solar and lunar components at Observatorio del Ebro for Nm data of 1979.

## hpF2 (1979)

ALL DATA
========
134 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 8.6 | 32.3 | 1.78 | 85.6 | 0.9 | 3.4 | 1.94 | 317.9 |
| 2 | 7.3 | 27.4 | 0.82 | 48.3 | 0.5 | 2.0 | 0.86 | 268.3 |
| 3 | 2.6 | 9.7 | 0.68 | 227.5 | 0.1 | 0.5 | 0.70 | 172.9 |
| 4 | 2.2 | 8.1 | 0.61 | 176.7 | 0.4 | 1.4 | 0.62 | 145.5 |

## SLAB-THICKNESS (1979)

ALL DATA
========
176 DAYS

| HARM | SOLAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG | LUNAR TERMS AMPLITUDE % | VAL. | P.ERR | PHASE DEG |
|---|---|---|---|---|---|---|---|---|
| 1 | 9.5 | 11.7 | 0.92 | 142.7 | 0.7 | 0.9 | 1.00 | 346.1 |
| 2 | 0.6 | 0.8 | 0.54 | 263.9 | 0.3 | 0.4 | 0.56 | 11.7 |
| 3 | 7.2 | 8.8 | 0.38 | 228.6 | 1.1 | 1.4 | 0.40 | 307.1 |
| 4 | 1.6 | 1.9 | 0.35 | 144.9 | 0.9 | 1.1 | 0.36 | 213.2 |

**Table VI. -Solar and lunar components at Observatorio del Ebro for data of 1979.**

and $\tau$ by seasons have been emitted because of the small number of data involved.

As can be seen, the results of foF2 and Nm are very similar, therefore, we shall discuss the results of Nm. We shall use the results obtained for foF2 only when comparing with authors that analyse this parameter.

The second lunisolar harmonics of Nm and TEC are always significant except in summer, when only the third harmonics are significant. The third harmonics of both parameters are also significant when the data of the whole year are taken together. There are two harmonics that are significant in TEC and not in Nm, the third harmonic of winter and the first one in equinoxes. Nevertheless the phases of these two harmonic of Nm are very near to the corresponding oner of TEC. For an easier comparison of the results of the two parameters, the dials of the lunar harmonics are shown in figs. 2-4 . The dials corresponding to summer have been omitted because of their small significance. As can be seen, all significant harmonics and most of the non significant ones are very similar and practically all the harmonics of a parameter are within the error circle of the corresponding harmonic of the other parameter.

The results of the slab-thickness, that appear in table VI, do not show a significant lunar influence. However, the number of data amalised is not enough to conclude the non existence of such an effect.

The number of data of hpF2 that we have analysed is also small but the results appearing in table VI show that the second lunar harmonic is significant.

The time of the maximum variation of te second lunar harmonic deduced from the results of tables V and VI is 9.9hr. for foF2 when all data are considered and 6.1hr. for hpF2, so that the difference between both is 3.8hr. Matsushita (1967) finds that for midlatitude stations the maximum lunar variation of foF2 occurs at about 10hr., like the value of Ebro. For hmax F2 (equivalent to our hp) he finds that the maximum variation takes place between 6-7hr. that agrees with our results. According to the same author, the difference between the phases of

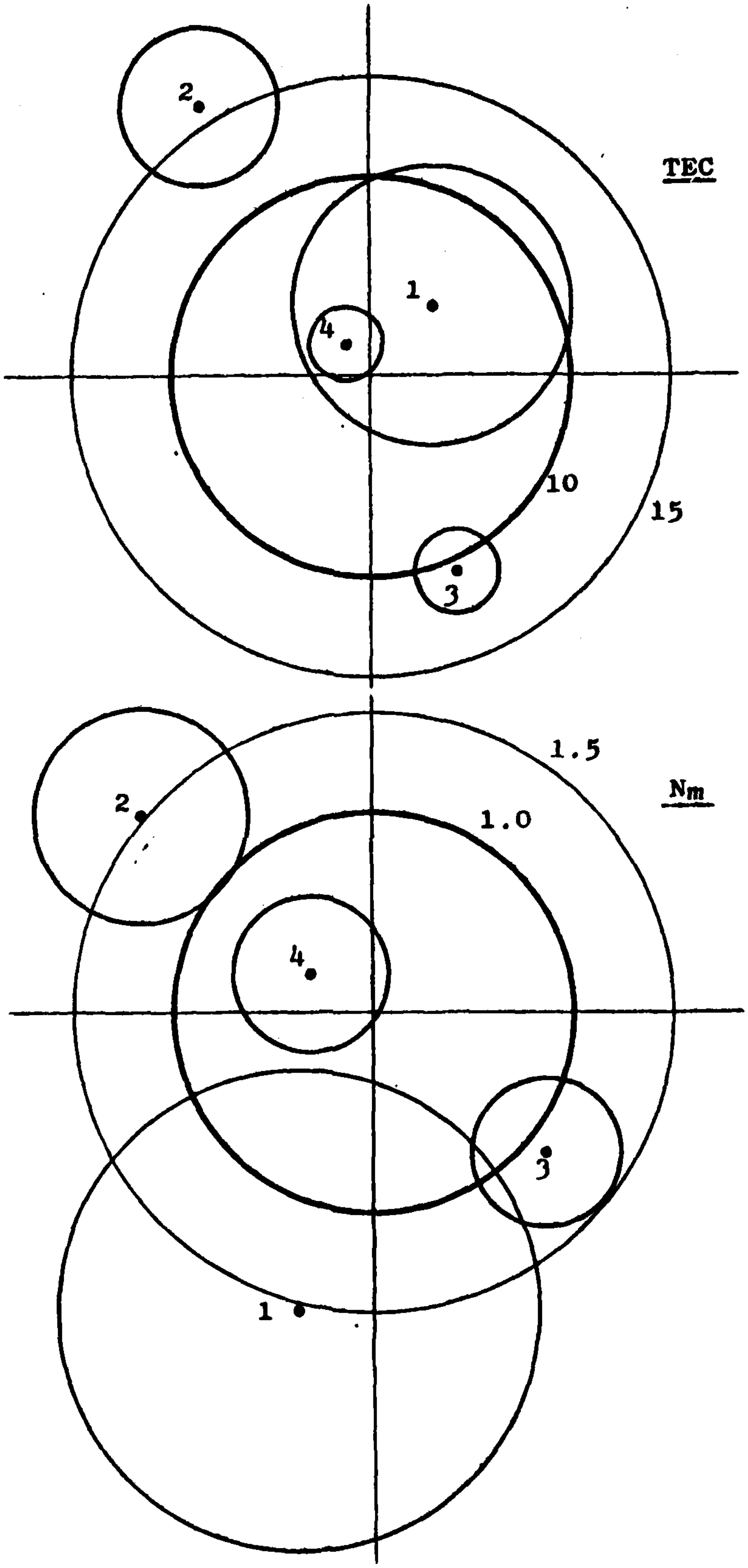



Fig. 2. - Lunar harmonics for data of 1979.

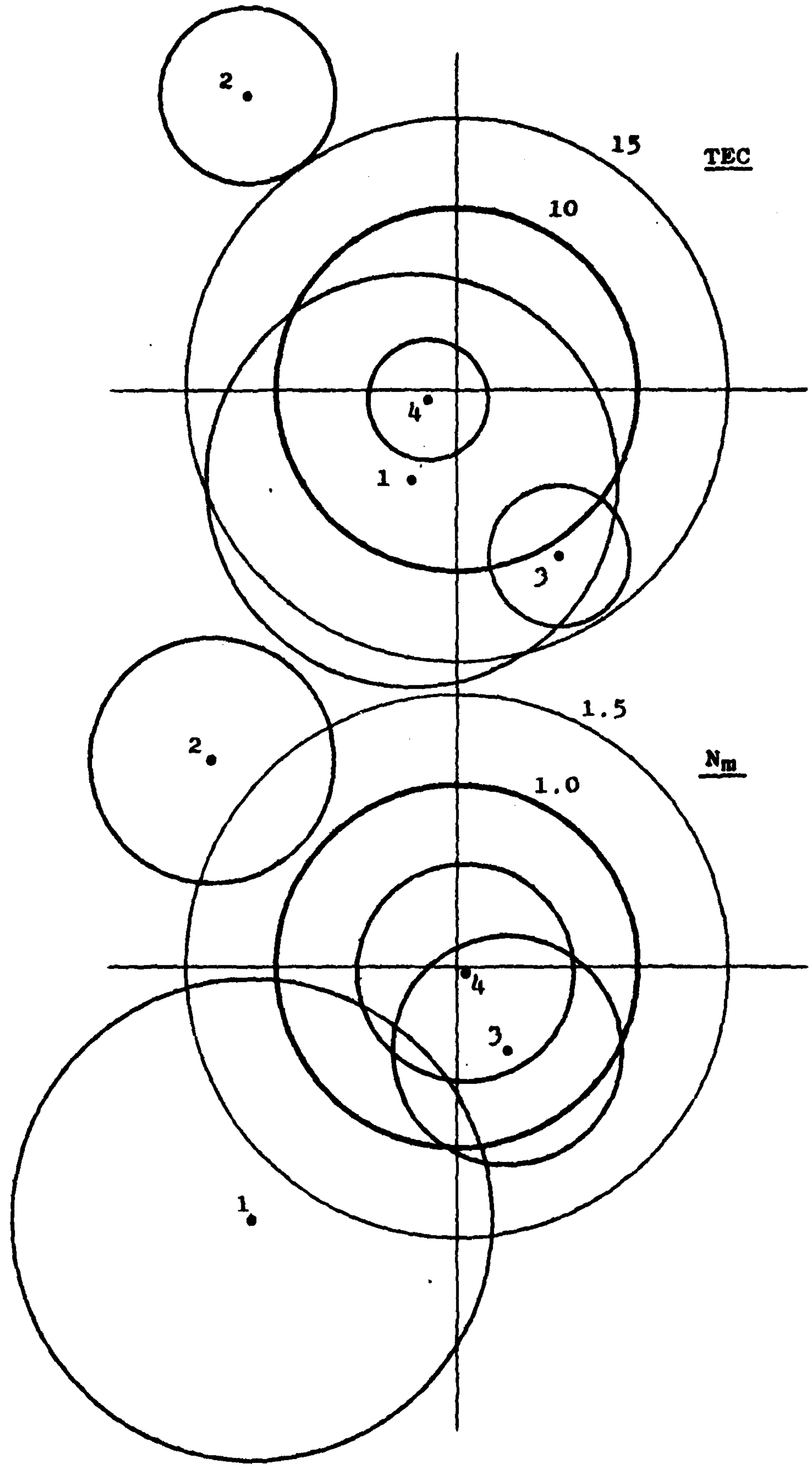
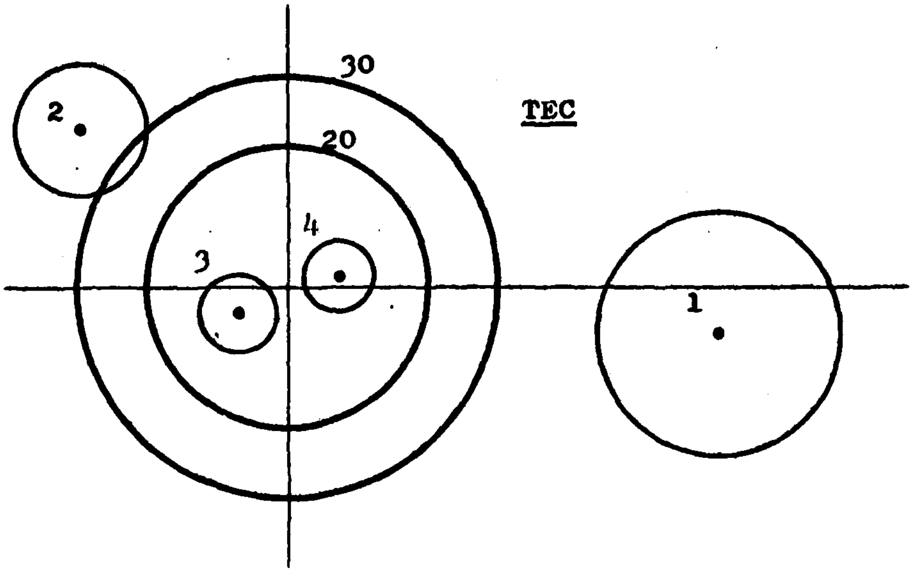



Fig. 3. - Lunar harmonics for winter 1979.



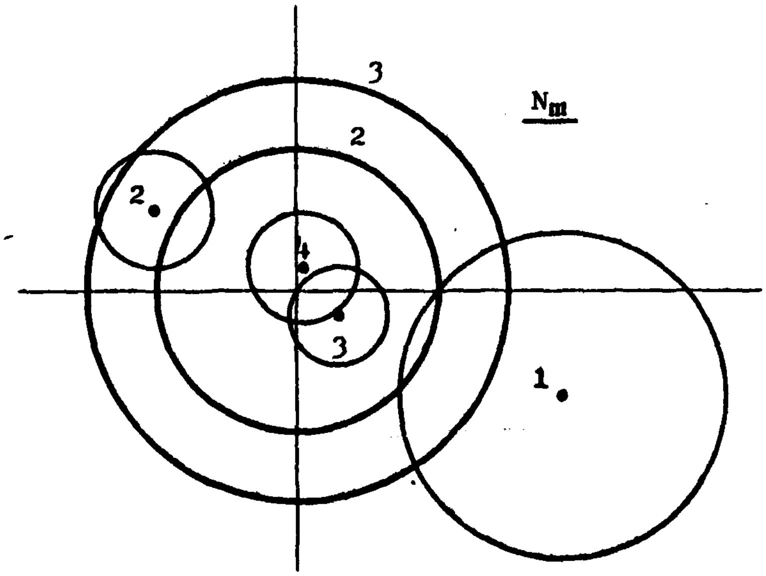




Fig. 4. - Lunar harmonics for equinoxes 1979.

foF2 and hmaxF2 for the same station is about 3hr., slightly lower than the value found for Ebro. Handa (1978) finds at two midlatitude stations (Wakkanai and KoKubunji) for the time of maximum variation respectively 8.9 and 8.5hr. for foF2 and 5.2 and 3.0hr. for hmF2 (although he gives these last two values as not significant). The values of Wakkanai are a little lower than our results but the difference between the phases of both parameters is similar to the one found for Ebro. The values of KoKubunji are also smaller than those of Ebro but the difference of phases is bigger.

In fig. 5 the lunar variation of the first four harmonics corresponding to all data of 1979 of TEC and Nm are shown for 15 lunar days of different lunar ages, from new to full moon. The time of the solar noon has been marked. As can be seen, the variation is very similar in both parameters, showing the maximum amplitude during solar day light hours, near solar noon. Since the data have been obtained through very different methods, the similarity of the results seems to enforce their significance.

Fig. 6 corresponds to the variation of the first four harmonics of Nm and hpF2 in a representation similar to the one of fig. 5. The 4hr. time lag (almost out of phase) between the phases of the second harmonic of both parameters is apparent. The maximum amplitude of the hpF2 variation takes place several hours away from the solar noon. This effect is better seen in fig. 7 where the same variation is shown against solar time. The maximum amplitude of hpF2 takes place near and usually before 6hr., while the maximum amplitude of Nm remains between about 6hr. and a little after noon. The maximum amplitude of the variation occurs at about 17 hr. for Nm and about 16hr. for hpF2.

It seems that there is another effect that appears in fig. 7. From 10hr. on, and for about 12 hours every day, the variation of hpF2 seems to be in phase with that of Nm, altough the amplitude is smaller. This effect can be caused by the relatively strong 4th harmonic of hpF2 that is in phase with the corresponding one of Nm. The fact that it always begins at the same solar time indicating a solar control. Honda and Maeda (1978) numerically calculate the lunar tide from the electro-

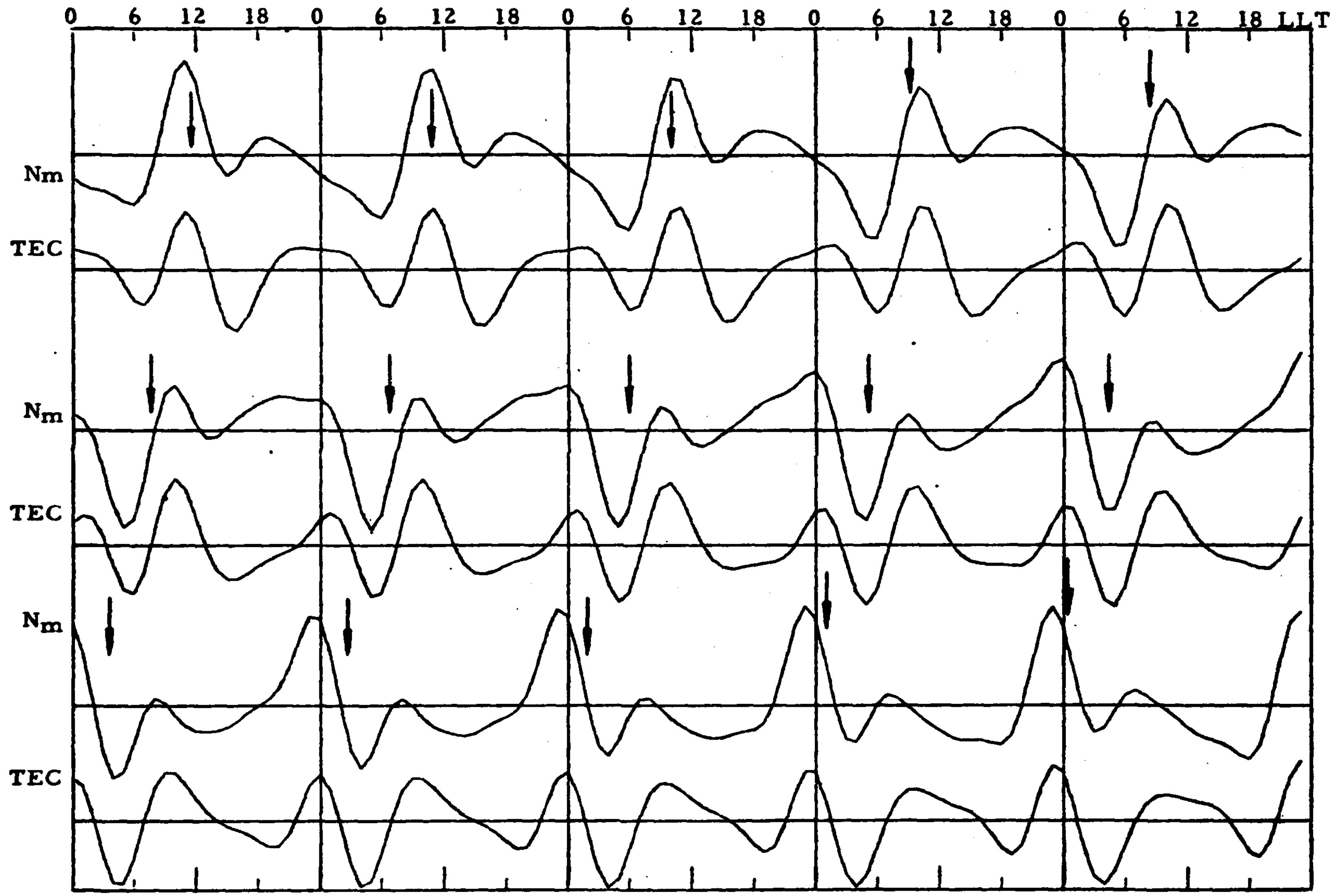



Fig. 5. - Lunar variation of Nm and TEC for 15 lunar days of different lunar age (from =0 to =12)
The arrows indicate local solar noon.

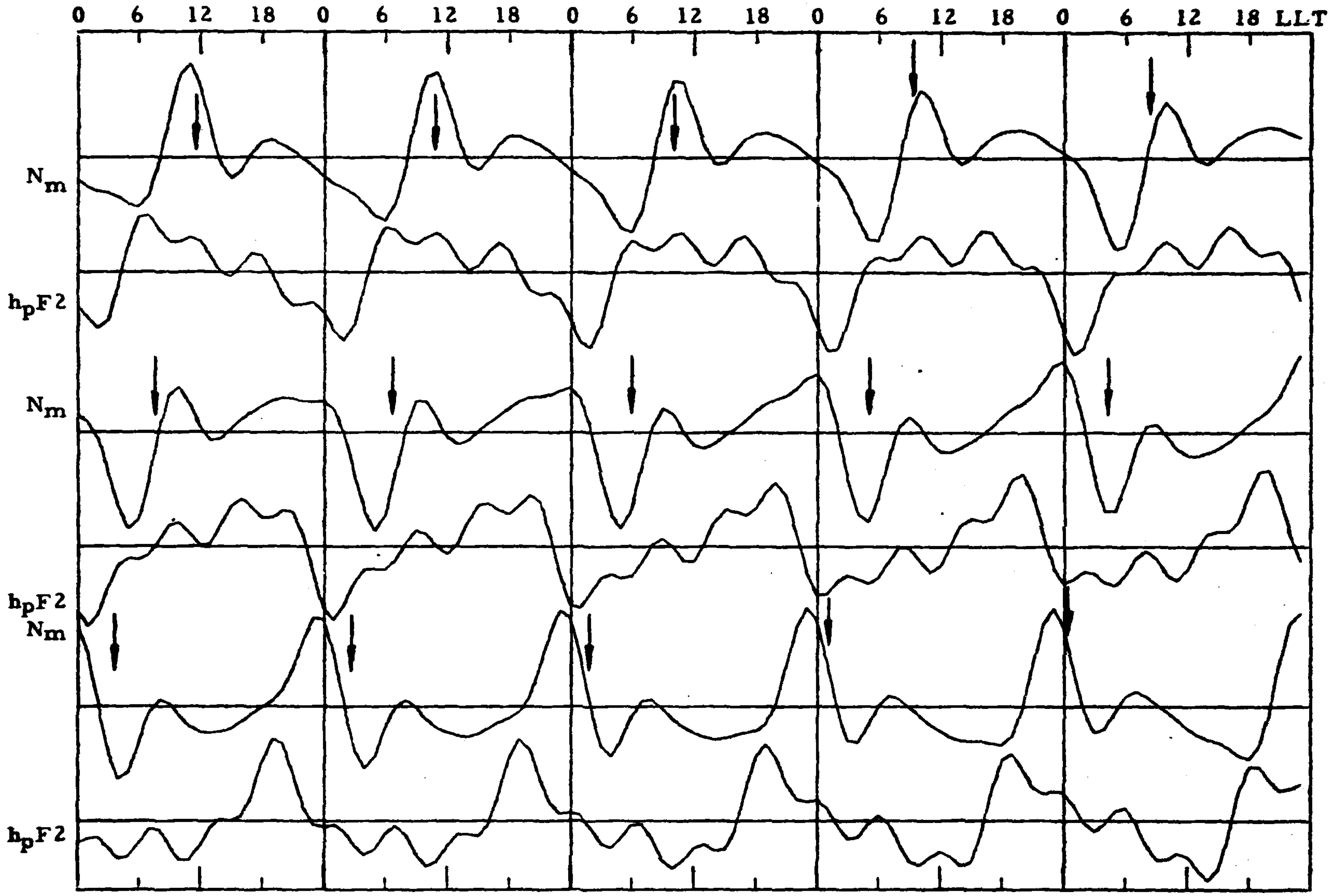



Fig. 6. - Lunar variation of Nm and hpF2 for 15 lunar days of different lunar age (from =0 to =12). The arrows indicate the solar local noon.

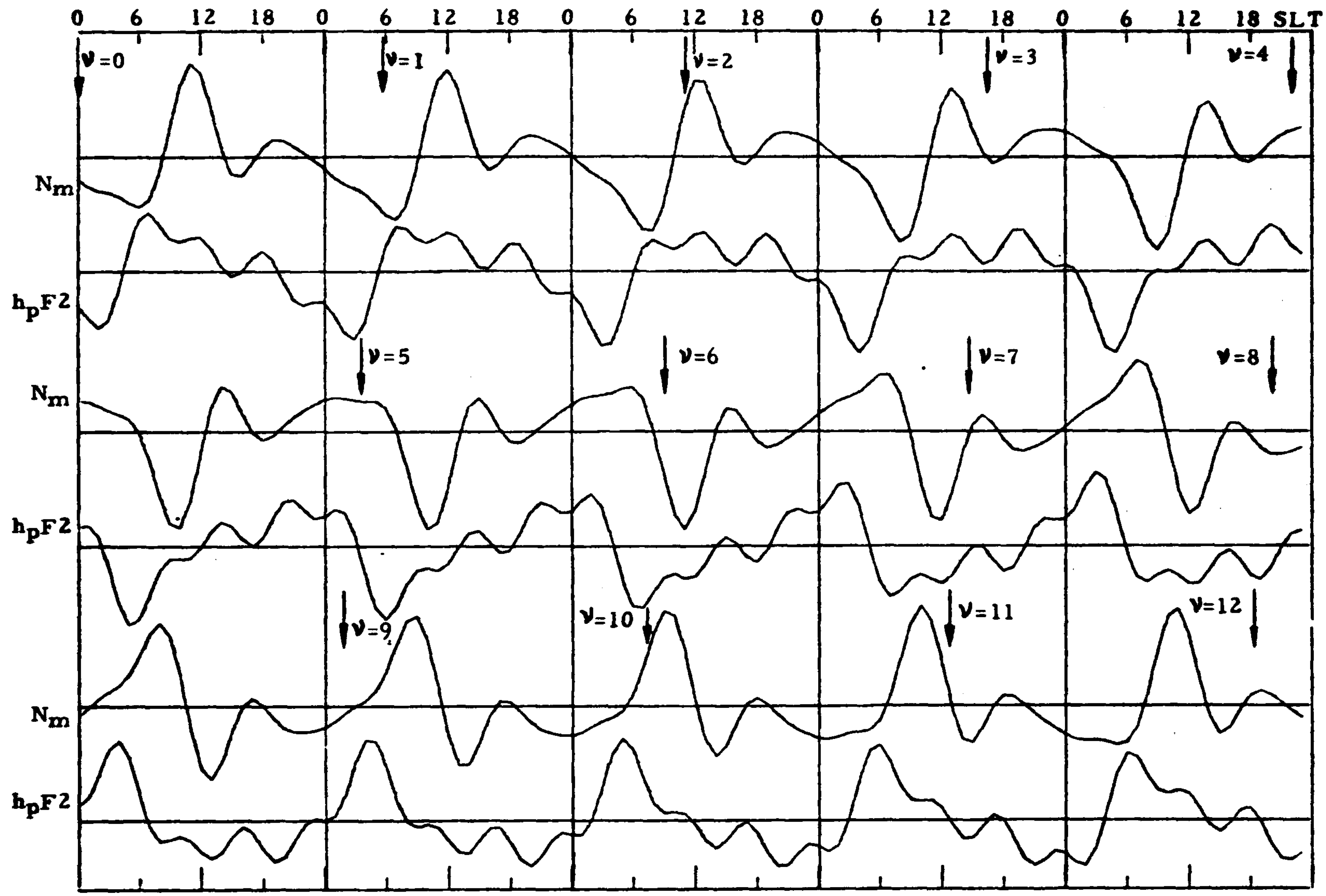



Fig. 7. - Lunar variation of Nm and hpF2 for 15 solar days of different lunar age (from =0 to =12)

magnetic drifts ossociated with the lunar electric current in the dynamo region. They find that the lunar variation of NmF2 is in phase with the lunar variation of hmF2 during day and ont of phase during night. This result is similar to the one we find from fig. 7, but the periodes of similar phase and almost out of phase we find are not centered in the day but shifted a little Towards the later hours.

SEMIMONTHLY LUNAR VARIATION.

The semimonthly lunar variation of the TEC data for every solar hour have been obtained for Hamilton and Ebro by the procedure described by Alberca et al. (1980). The results for the two year's data and for the different seasons are shown in figs. 8-11.

In general, at both stations, the amplitude increases in the morning and diminishes in the evening, having higher values during day than during night. Only in summer the amplitude of Ebro has the minimum value at 10 SLT; in all other cases, the minimum takes place before 6 SLT. Summer is also the season when the amplitude shows two clear maxima in both stations: at 9 SLT and 18 SLT in Hamilton and at 2 SLT and 16 SLT in Ebro.

The phase goes usually twice through zero: between 8 and 11 SLT and at the end or the beginning of the day. When this pattern is not followed (like at Hamilton in winter or at Ebro in Equinoxes), the phase remains nearly constant (near 0 or 12) till abont 8 SLT when it begins increasing more or less regularly till the end of the day.

The same analysis, has been applied to the 1979 Ebro data of TEC, Nm and hpF2. The results are shown in figs.12-14. We are not giving the results of the seasonal distribution of the Nm and hpF2 because of the small number of data of such a distribution.

The results of TEC are, of course, very similar to the ones obtained with 2 years data. In summer, however, (fig.13) both maxima are delayed; the first one to 7 SLT and the second one to 16-17 SLT. Besides, the amplitude of both maxima is nearly

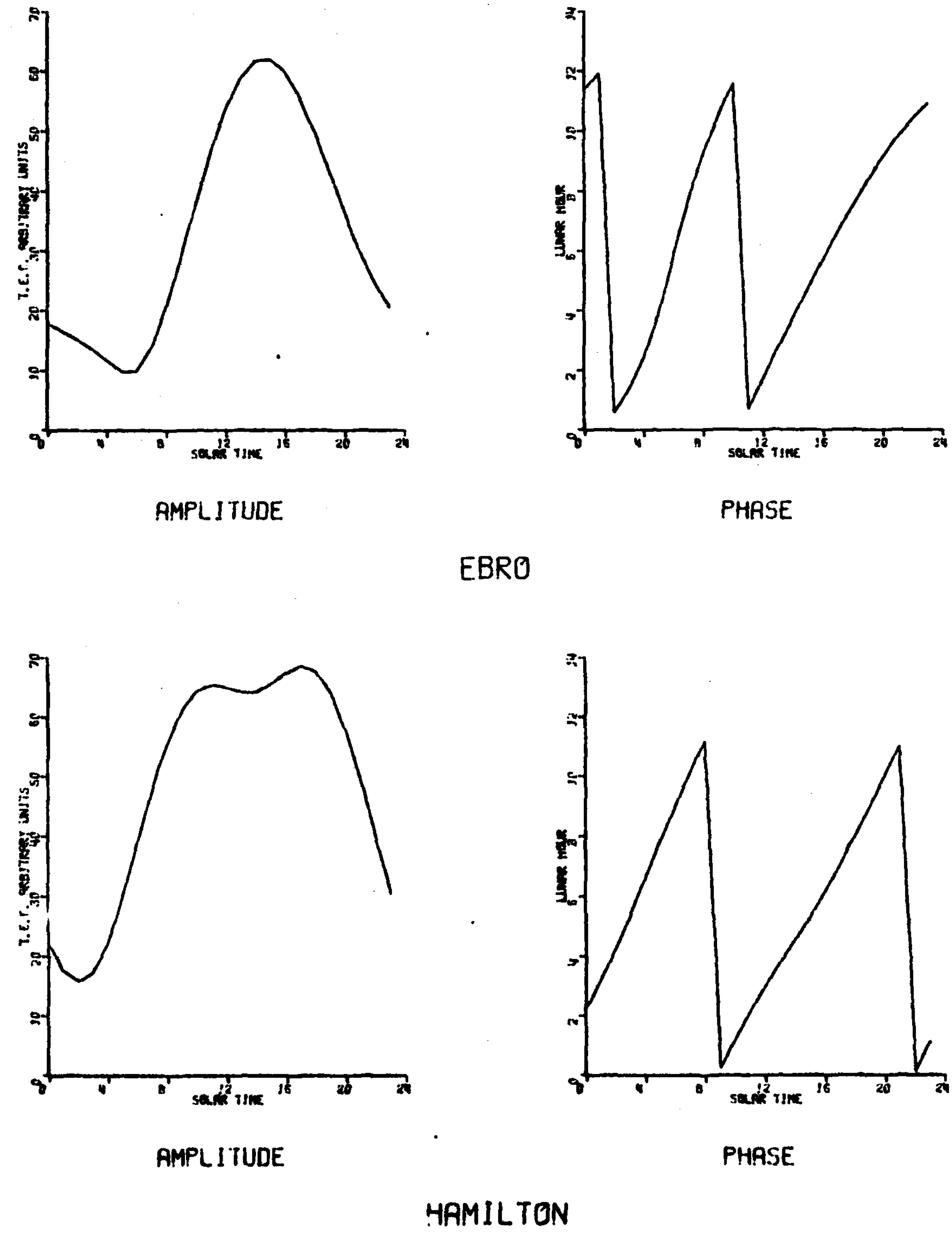



**Fig. 8. - Solar variation of the semimonthly lunar tide for TEC data of two years.**

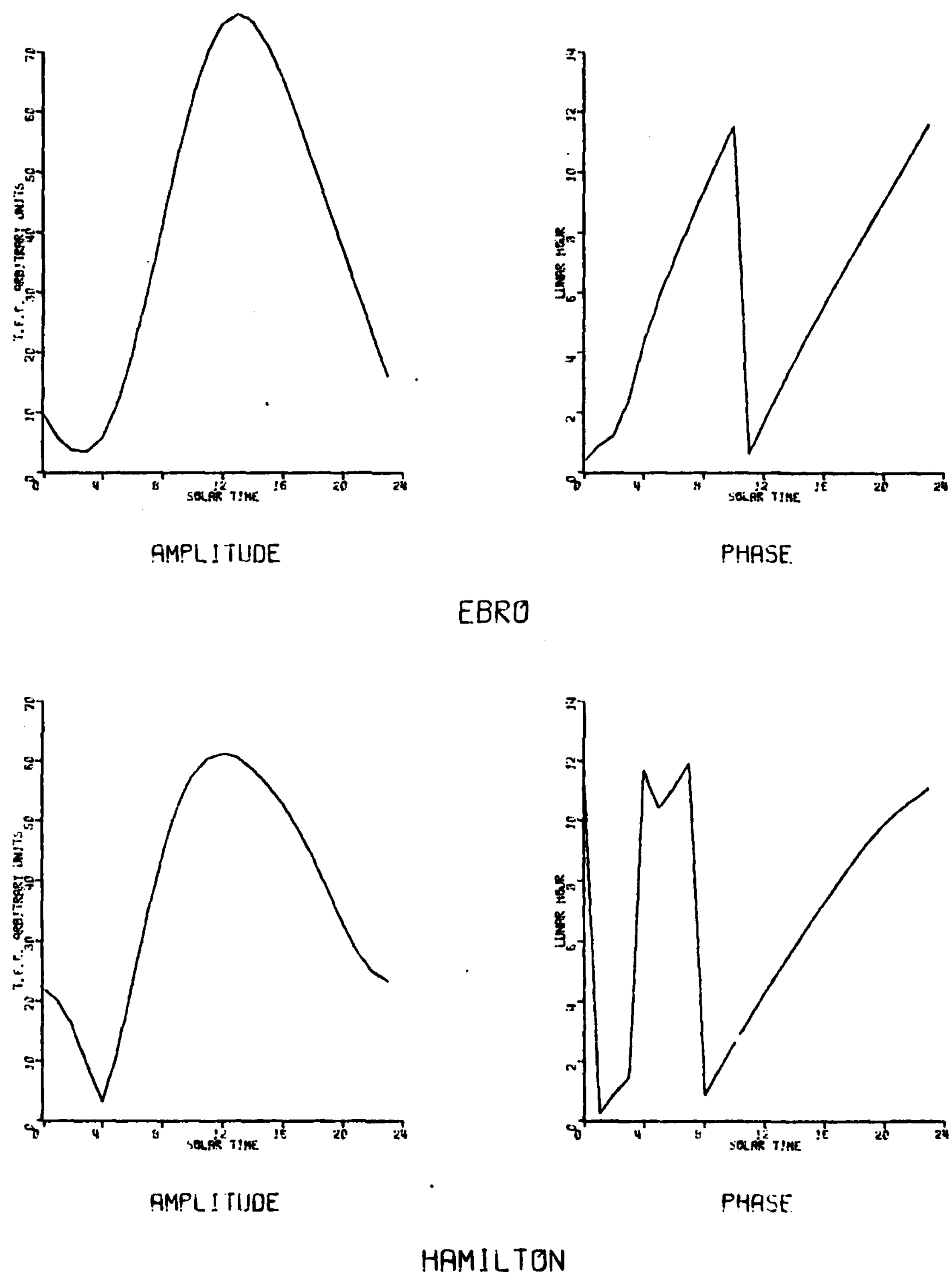



Fig. 9. - Solar variation of the semimonthly lunar tide for TEC winter data of two years.

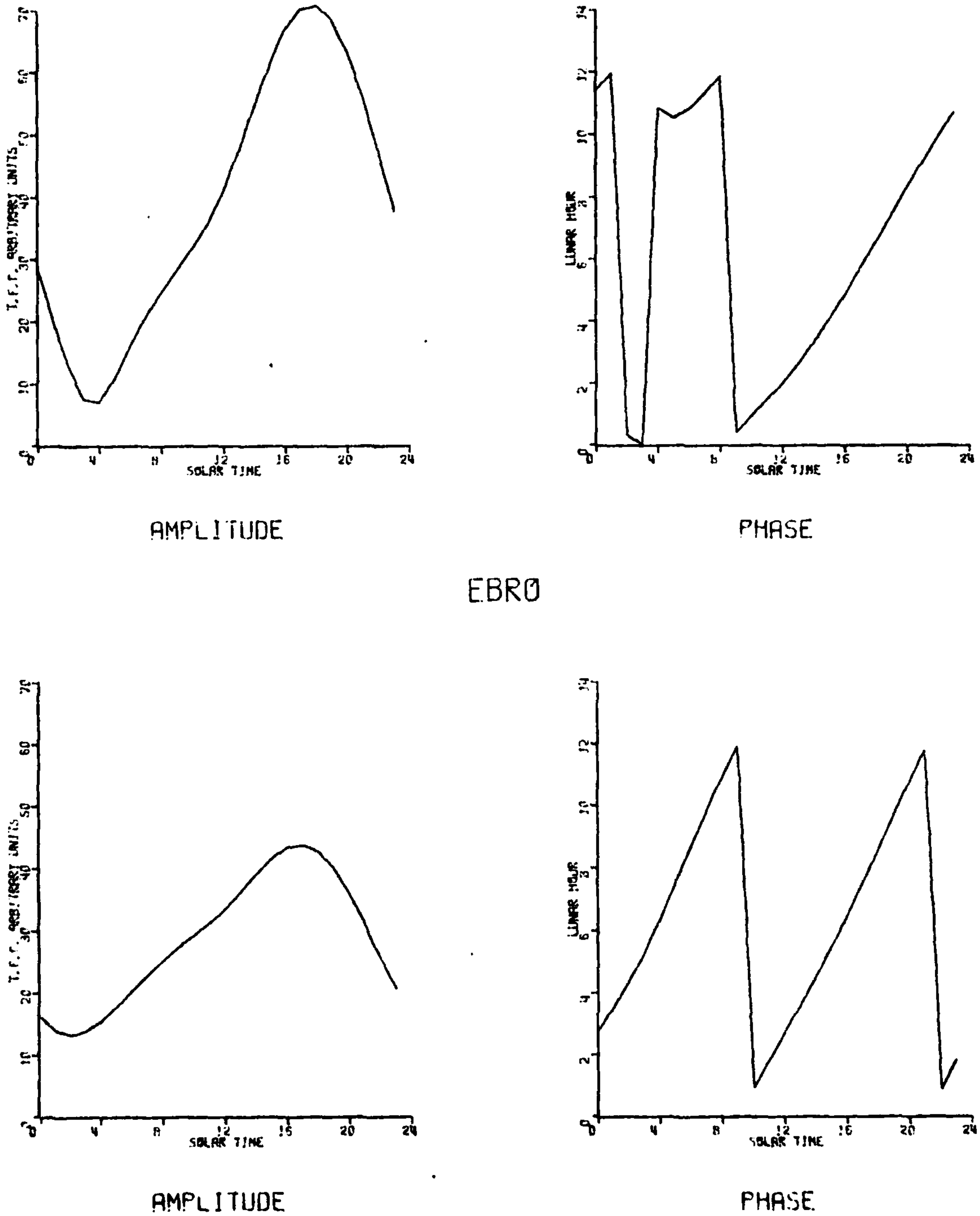



**Fig. 10. - Solar variation of the semimonthly lunar tide for TEC equinoxes data of two years.**

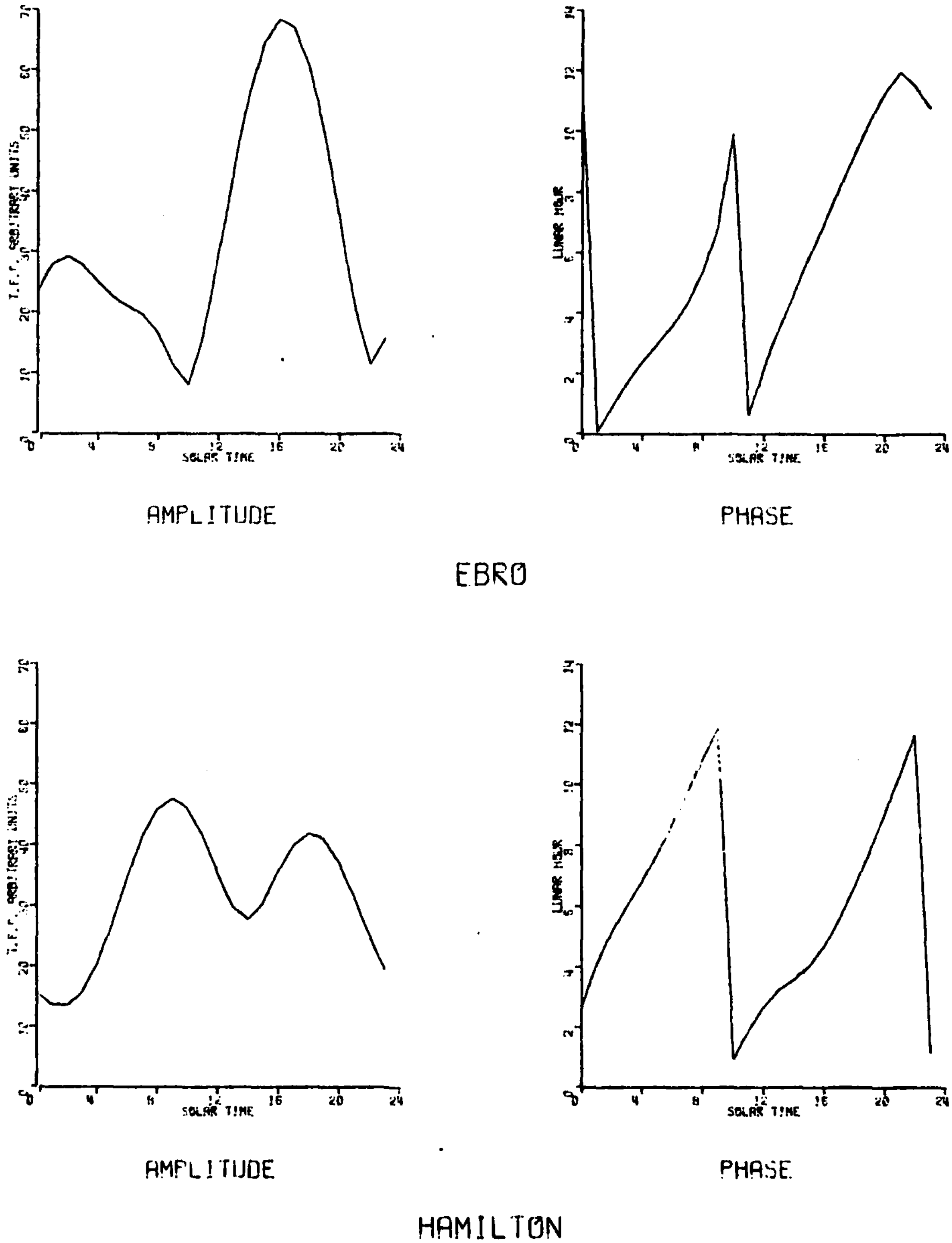



Fig. 11. - Solar variation of the semimonthly lunar tide for TEC summer data of two years.

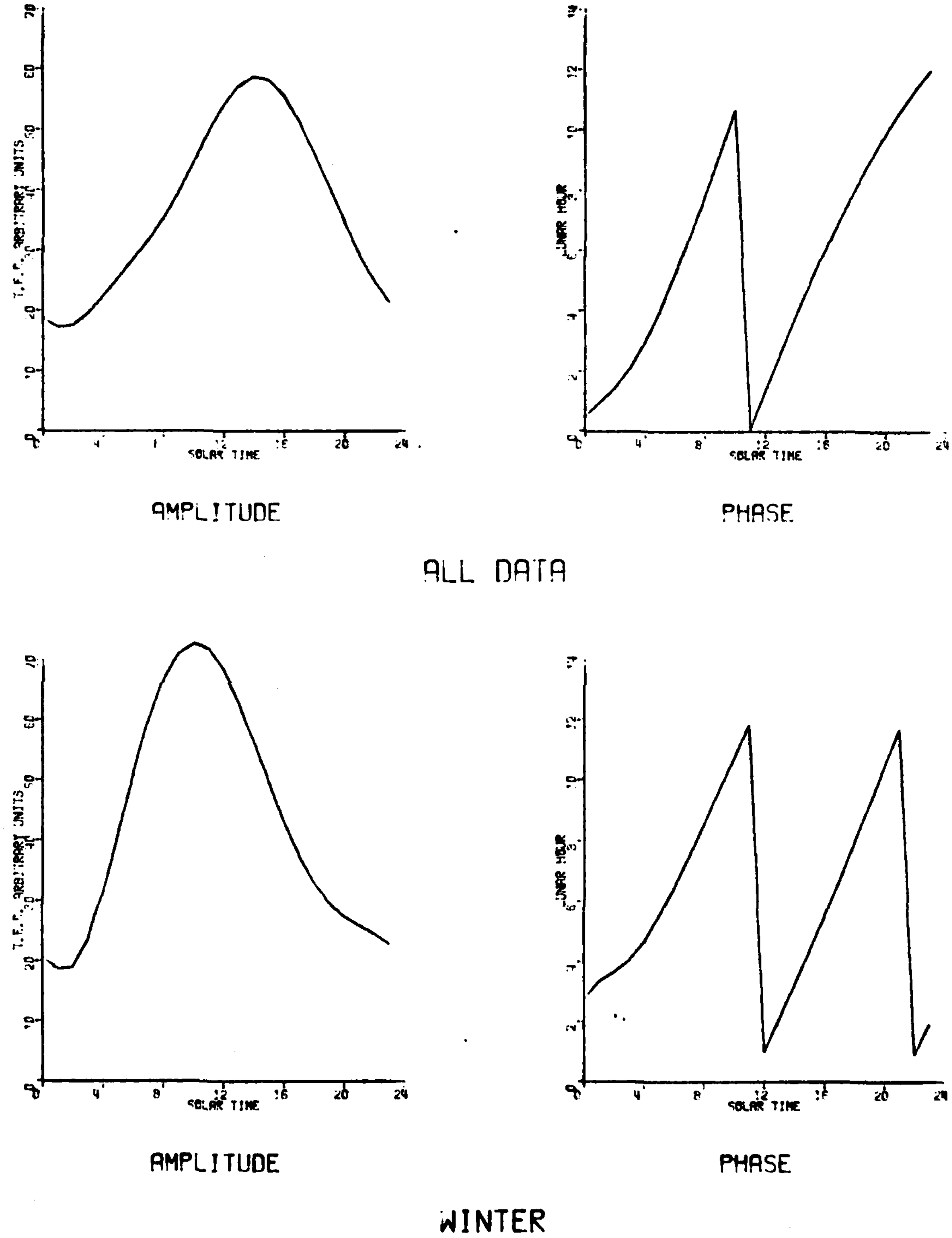



Fig. 12. -Solar variation of the semimonthly lunar tide for 1979 TEC data

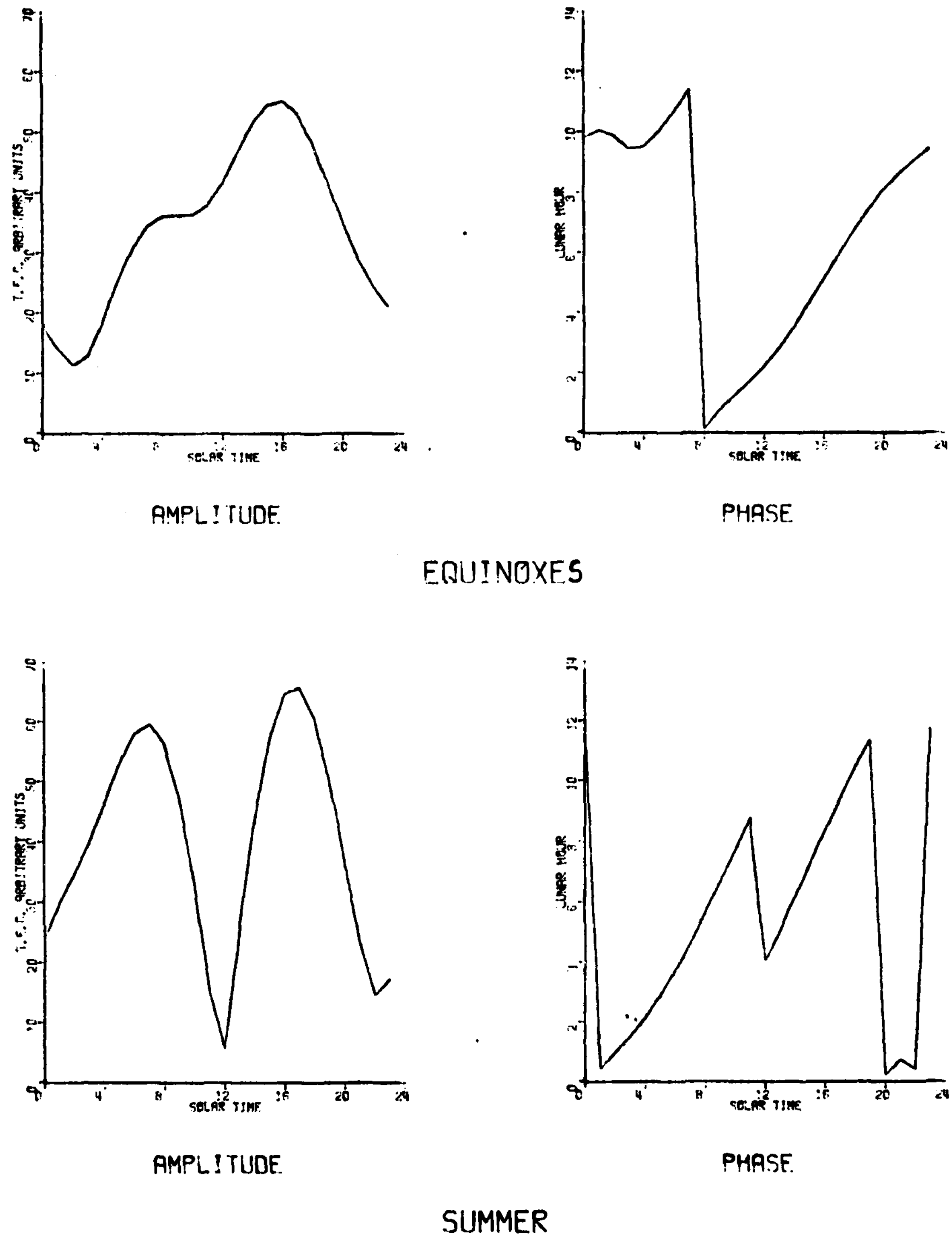



**Fig. 13. -Solar variation of the semimonthly lunar tide for 1979 TEC data.**

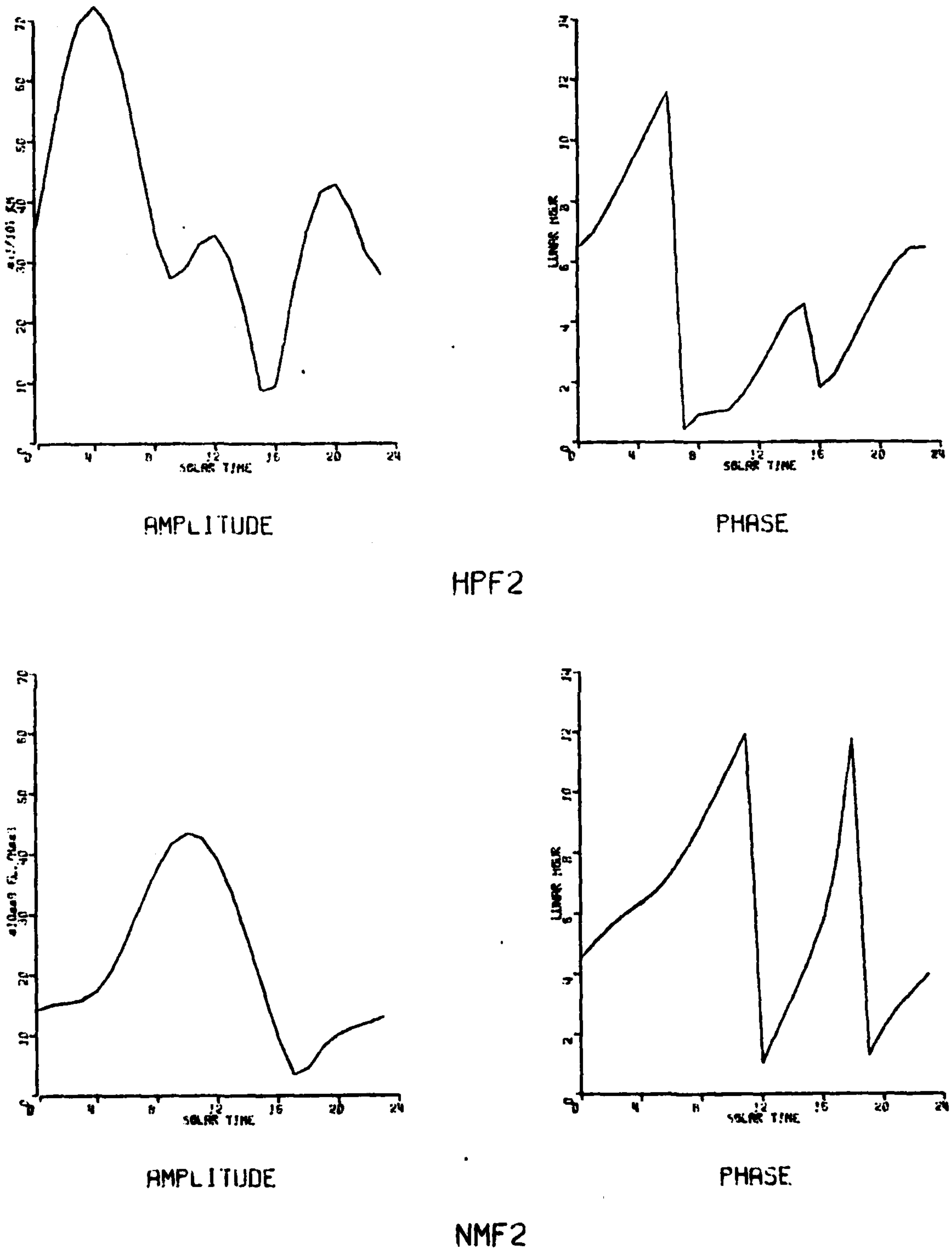



Fig. 14. - Solar variation of the semimonthly lunar tide for data of 1979.

equal, so that the similarity with Hamilton results has increa sed. The phase in summer has a sudden decrease at about 12 SLT that does not appear in other cases. Nevertheless, the signifi cance of the summer results is very low, so that these featu- res have to be taken cautiously.

The maximum amplitude of the semimonthly lunar variation of Nm (fig.14) occurs a little earlier than the corresponding maximum of TEC (fig.12). Also the minimum, that for the parame ter Nm takes place at 17-18 LST, seems to have been delayed to the early hours of the (next) morning for TEC. Similarly the night zero of the phase of Nm occurs at 19 LST while the zero of TEC occurs later, at 24 LST.

The variation of the amplitude of hpF2, besides the main maximum at 4 SLT and the secondary one at 20 SLT has a small maximum al 12 SLT. The main minimum takes place at 15-16 SLT, very near the minimum of the amplitude of Nm. These amplitude variations can be seen also looking at the changes of amplitu de from one day to another at a fix solar time in fig. 7.

The phase of the semimonthly lunar variation of hpF2,that goes through zero between 6 and7 SLT, has a sudden decrease bet ween 15 and 16 SLT, just when a increase in the slope of the phase of Nm begins. Handa (1978), finds an amplification of the semimonthly lunar tide of foF2 and hmF2 at about 2-6hr in the morning and about 18-22hr in the evening at Wakanaii.He finds a similar amplification at KoKubunji except for foF2 in the morning. We find this effect only in the hpF2 variation and in the variation of the two year TEC data of Ebro in summer. The variation of the other parameters in summer ( even Nm and hpF2 not shown here) is similar t that, but the morning maximum is a little delayed with respect to the results of Handa.

CONCLUSION.

Taking the phase as the time of the maximum variation, the analysis of two year of TEC data by the Chapman-Miller method gives a value of the phase for the second harmonic of the diurnal lunar tide that goes from 10hr in summer to 11hr. in equinoxes at Ebro, and from 8,5hr in winter to 10hr in summer at Hamilton. When the data of the two years are taken together the phase is 10.8hr al Ebro and 9.5hr at Hamilton. The amplitude of this harmonic is maximum in winter (2%) at Ebro and maximum in equinoxes (4 % ) at Hamilton. The minimum amplitude is reached in summer at Ebro and in winter at Hamilton.

The Chapman-Miller method has also been applied to several ionospheric parameters recorded at Ebro during 1979. The phase of the second lunar harmonic is 10.3hr for NmF2 and 10.9hr.for TEC. The lunar variation of these two parameters, when the four lunisolar harmonics are considered, is very similar. This fact seems ro reinforce the significance of the results. Both parameters have the maximum amplitude of the second lunar harmonic in equinoxes, while the amplitude of this harmonic in summer is too small to be significant. The results for foF2 are also very similar to the results of NmF2, being the phase of the second lunar harmonic 9.9hr. The phase of the second harmonic of hpF2 is 6.1hr. about 4hr.less than the phase of Nm and foF2. When the first four lunisolar harmonics are taken into consideration, the maximum variation of hpF2 takes place near and usually before 6hr., while the maximum amplitude of Nm occurs between about 6hr. and a little after noon.

When we compare the lunisolar variation of Nm and hpF2 during several solar days of different lunar age, besides the 4hr. time lag between the phases of the second harmonics of both parameters, another effect seems to appear: for about half a day beginning at 1000 SLT the variation of both parameters seems to be in phase. The number of data is so small that we cannot say wether this is a real effect caused by the different response of the ionosphere between day and night or wether it is only

the result of the anomalously high amplitude of the 4th lunar harmonic of hpF2 in phase with the 4th harmonic of Nm.

The 'slab-thickness' of the ionosphere does not seem to have a clear lunar tide. Nevertheless the number of data used in this analysis is not enough to consider this conclusion as a final one.

The semimonthly lunar variation of TEC in Ebro and Hamilton shows a clear dependence of the solar time. The same thing happens to the NmF2 and hpF2. In general the amplitude increases during the morning and decreases during the evening. Only hpF2 always, and the other parameters in summer, present two maxima with a secondary minimum near noon. The minimum of the amplitude of TEC occurs at the first hours of the day while for Nm and hpF2 it takes place respectively at 17 SLT and 15 SLT. The phase goes usually twice through zero, except for hpF2. One zero of the phase occurs between 8 and 12 SLT while the other one takes place near midnight. The zero of the phase of hpF2 occurs at 7 SLT.

The probable errors of the different harmonics are not low enough to give more detailed accurate conclusions. It seems that a previous filtering of data is needed in order to eliminate anomalous values without masking the small real lunar variation, and this probably requires a bigger ammount of initial data.

## REFERENCES


ALBERCA, L.F., J.O. CARDUS and E. GALDON (1980): Total electron content lunar variation at two midlatitude stations. Sc. Rep. nº AFGL.

HANDA, S.(1978): The lunar tide of the ionospheric F2 region in Japan. J.Atm. Terr.Phys. 40, 973-976.

HANDA, S. and H. MAEDA (1978): A numerical study of the lunar tide in the mid-latitude F2 region of the ionosphere. I. Oscilations of the electron density. J. Atm. Terr. Phys. 40, 395-404.

MALIN, S.R.C. and S. CHAPMAN (1970): The determination of lunar daily geophysical variations by the Chapman-Miller method. Geophys. J.R. Astr. Soc. 19, 15-35.

MATSUSHITA, S. (1967): Lunar tides in the ionosphere. Handbuch der Physik XLIX/2, 548-602.

SHATTEN, K. H. and M. MENDILLO (1980): Short term periodities in ionospheric total electron content. Annual Sci. Rep. 2, AFGL.

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. Report Number EOARD-TR-82-12 | 2. Govt Accession No. ADA117689 | 3. Recipient's Catalog Number |
| 4. Title (and Subtitle) LUNAR VARIATION OF SEVERAL IONOSPHERIC PARAMETERS | | 5. Type of Report & Period Covered Interim Scientific Report 1 Sep 79 - 31 Aug 81<br>6. Performing Org. Report Number |
| 7. Author(s) L.F.ALBERCA ; J.O.CARDUS ; E.GALDON | | 8. Contract or Grant Number AFOSR-79-0114 B |
| 9. Performing Organization Name and Address OBSERVATORIO DEL EBRO ROQUETES (Tarragona) SPAIN | | 10. Program Element, Project, Task Area & Work Unit Numbers |
| 11. Controlling Office Name and Address AIR FORCE GEOPHISICS LABORATORY HANSCOM AIR FORCE BASE MASSACHUSETTS 01731 | | 12. Report Date 30 Sep 81<br>13. Number of Pages 30 |
| 14. Monitoring Agency Name and Address | | 15. |

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

18. Supplementary Notes

19. Key Words

Total electron content, Lunar tide , F2 layer


20. Abstract

The first four harmonics of the diurnal lunar variation and the semimonthly lunar tide for two years TEC data at Ebro and at Hamilton, and for some other ionospheric parameter at Ebro have been obtained. For the parameters with sufficient number of data, the lunar harmonics for different seasons have always been obtained. The relation between the diurnal lunar variation of the height and the electron density of the maximum of the F2 layer seems to be solar dependent with a change of the phase at about 1000 SLT. The diurnal solar variation of the semimonthly lunar tide is also discussed.


FORM 1473

DAT
ILM